High-Frequency Channel Characterization Experiment

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LONG-TERM GOALS

The long-term goals are to advance our understanding of the nature of high-frequency (8-50 kHz) sound propagation in the ocean waveguide, with emphasis on surface, bottom, and volume effects on the forward propagated field.

OBJECTIVES

The central purpose of the High-Frequency Channel-Characterization Experiment (HFX) is to learn as much as possible about the channel impulse response (or transfer function) and its dynamics. Ideally, we would like to characterize the behavior as a function of 1) source/receiver geometry, 2) arrival angle, 3) carrier (central) frequency, 4) ocean volume structure, 5) bottom type, and 6) boundary dynamics, including effects of surface waves and bubbles.

APPROACH

A comprehensive experiment (KauaiEx) was planned for the Shallow Water Test Range of the Pacific Missile Range Facility (PMRF) using a variety of assets as described below. The experiment was conducted 22 June to 9 July and actually included several component experiments including HFX (High-Frequency Channel Characterization Experiment), SignalEx (Acoustic communications), and an

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acoustic tomography experiment. The general approach was to deploy as many environmental and acoustic sensors as possible to characterize both the ocean structure and the acoustic field structure.

WORK COMPLETED

A site was selected off Kauai in the Shallow Water Test Range of the Pacific Missile Range Facility as shown in Figure 1. Before deploying the moorings, a multibeam echo-sounder map of the area was conducted by the University of New Hampshire (Fig. 1 right). This map confirmed the pre-experiment planning, indicating that the mooring locations were precisely on the 100-m isobath of a drowned beach.

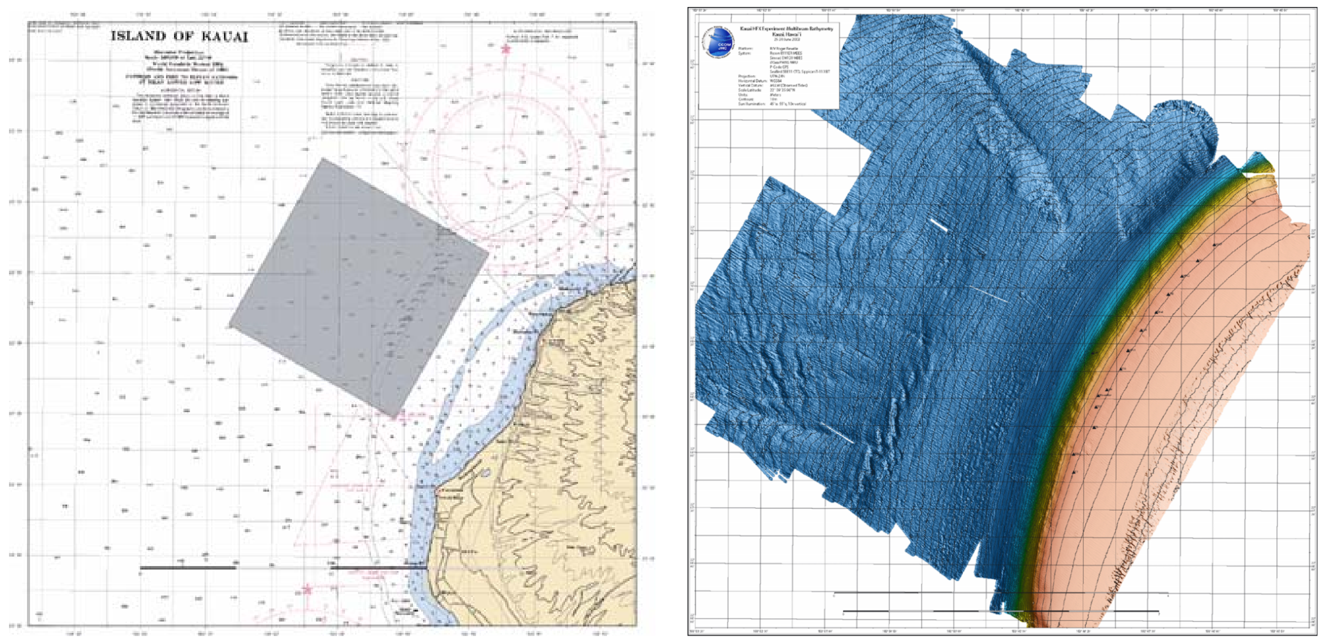

Figure 1: Experiment site off Kauai (left); Multi-beam echo sounder map (right).

Mooring locations had been selected with great care before the experiment to maintain a safe (200-m) standoff from all lines in the dense network of cables at the range. These mooring locations were treated as “sockets” with the actual equipment plugged into different locations during subsequent phases. An illustrative deployment is shown in Fig. 2.

The moorings included a large number of environmental sensors including a waverider buoy to measure the surface wave spectrum and an ADCP to measure the ocean currents. In addition, a curtain of self-recording thermistor strings was deployed along the propagation path to provide a detailed measurement of the ocean thermal structure. (Salinity variations were not anticipated to be important; however, CTD casts were conducted during the test and a set of self-recording CT sensors were also included in one of the thermistor strings.)

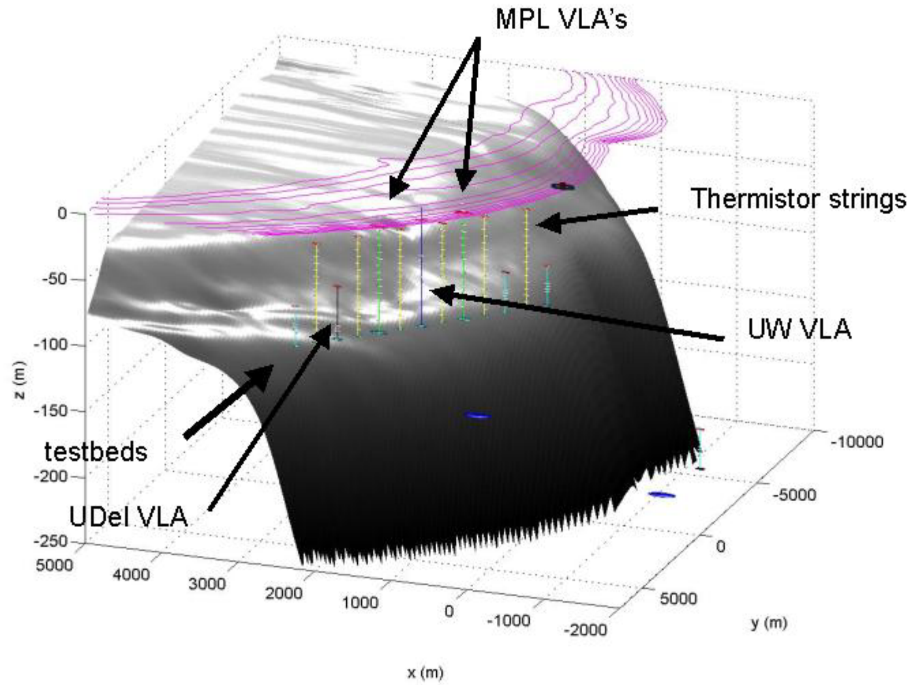

Figure 2 Sample mooring lay down showing environmental sensors and acoustic sensors along the 100-m isobath.

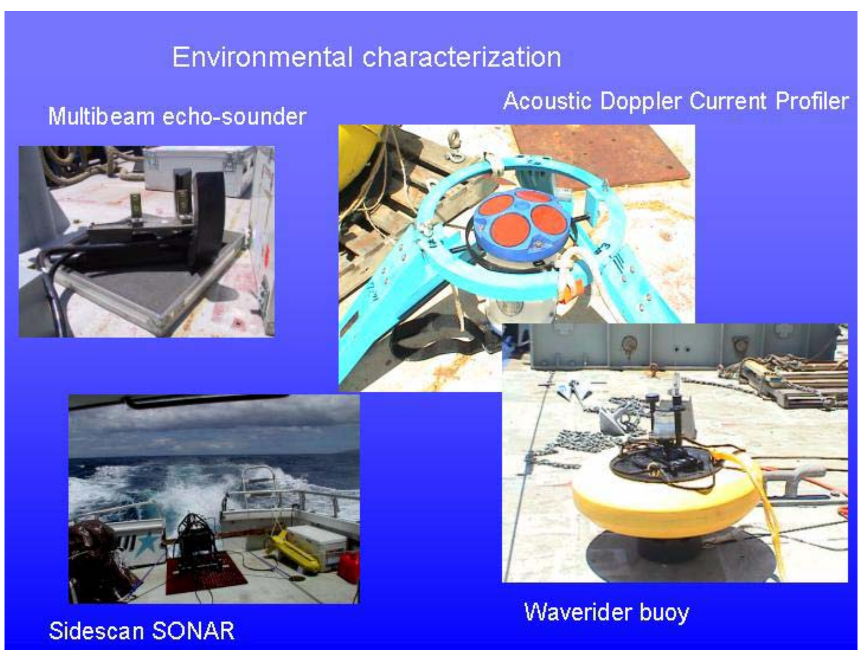

Figure 3: The environment was carefully measured during the experiment, using multibeam echo-sounder (high-precision bathymetry); acoustic Doppler current profiler (currents); sidescan SONAR (bottom images); waverider buoy (surface wave spectrum).

Since the environmental sensors could operate continuously for the duration of the experiment those moorings were placed at the very beginning. The acoustic sensors, which generally needed to be serviced on a 48-hour schedule, were deployed and recovered three times in the course of the experiment. These sensors included a variety of vertical line arrays provided by the various participants.

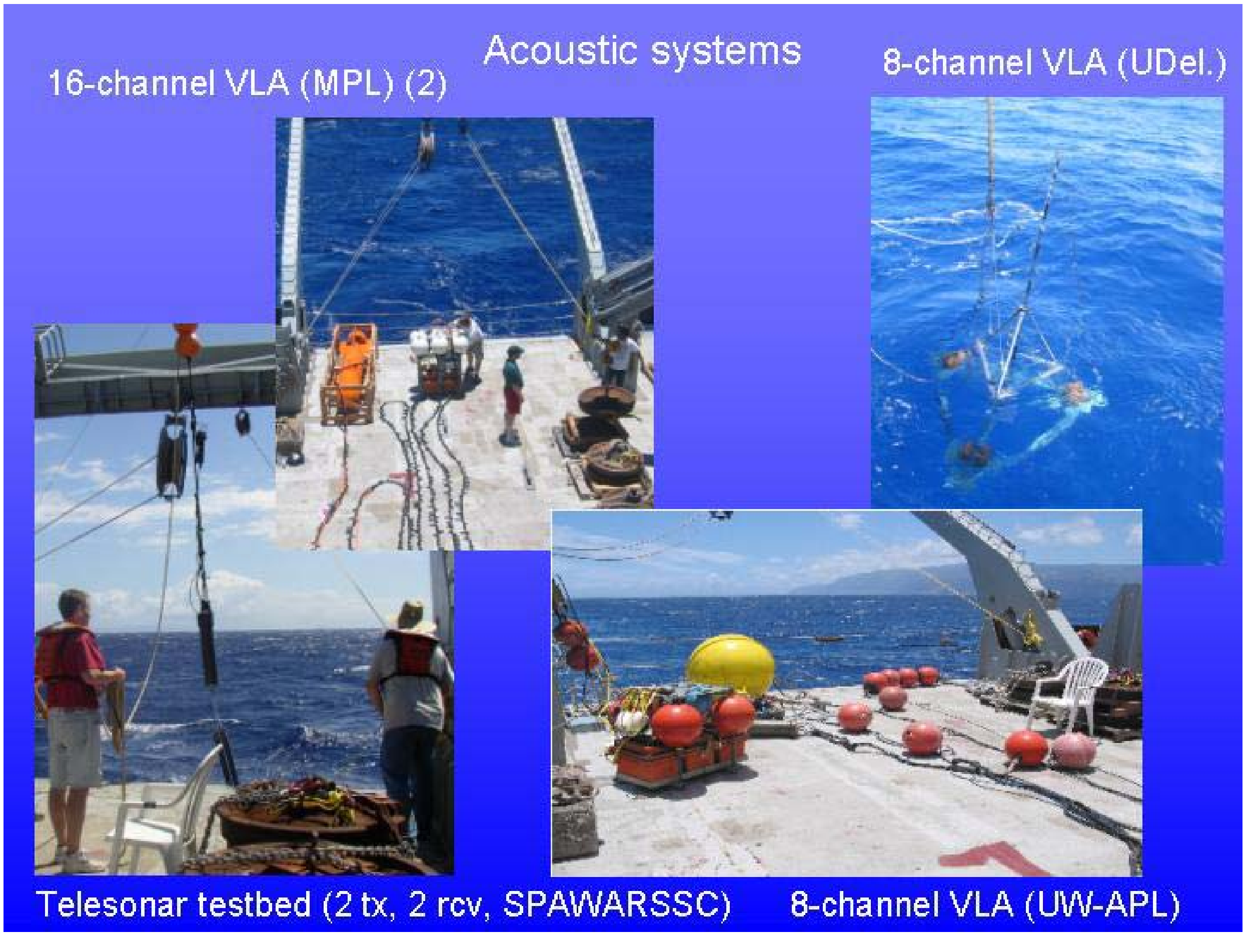

Figure 4: A wide variety of acoustic systems were also deployed, including 2 autonomous sources and vertical line arrays from several participating institutions.

RESULTS

Both the environmental and acoustic sensors performed almost flawlessly throughout the experiment, yielding over 2 terabytes of high-quality data. As the Kauai Experiment was only completed in July, much of the data analysis is just beginning. However, we can present some preliminary results here.

The waverider buoy (University of Delaware) provided nearly complete measurements of the surface wave spectrum over the 16 days of the experiment (Fig. 5). The general daily pattern was that the trade winds would start to pick up around noon and die down later in the evening. This same diurnal cycle is clearly visible in the surface wave spectrum. We also see the development of lower frequency swell during the period of 3-6 July, which we speculate is associated with a storm in the southern hemisphere.

A somewhat surprising feature of the site is shown in the thermistor string records (MPL and UDel) in Fig. 6. We had expected the greatest variability near the surface, associated with surface heating and mixing due to the trade winds. In fact, the bottom was the most variable section with fluctuations of several degrees (Celsius) over periods of a few hours. (This variability was first noted in the acoustic data and led us to conduct an intense channel probe test during the third deployment phase.)

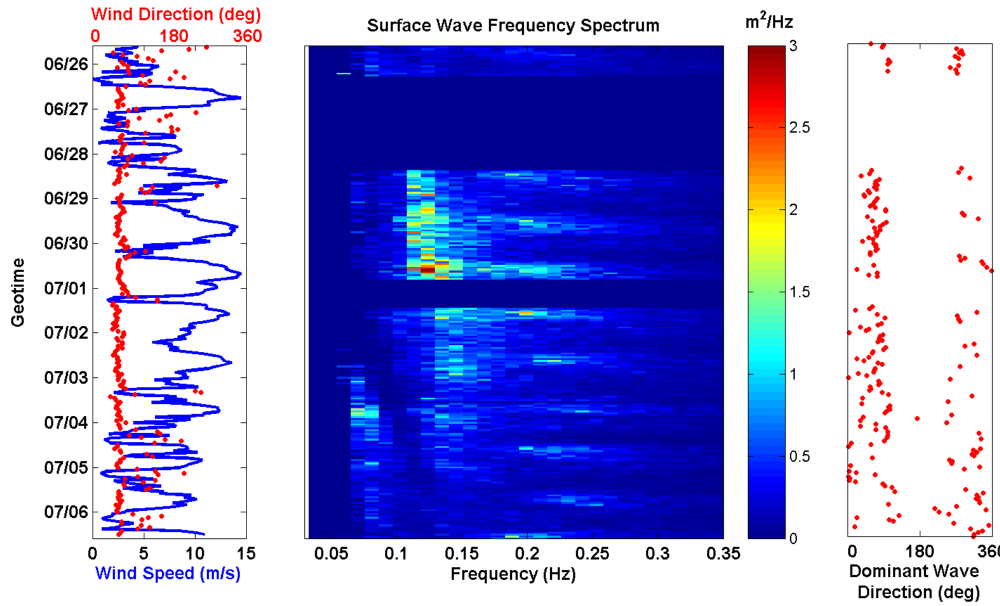

Figure 5: The diurnal pattern of the trade winds is clearly visible in the wind speed record on the left. This in turn is echoed in the surface wave spectrum recorded on the waverider buoy (center).

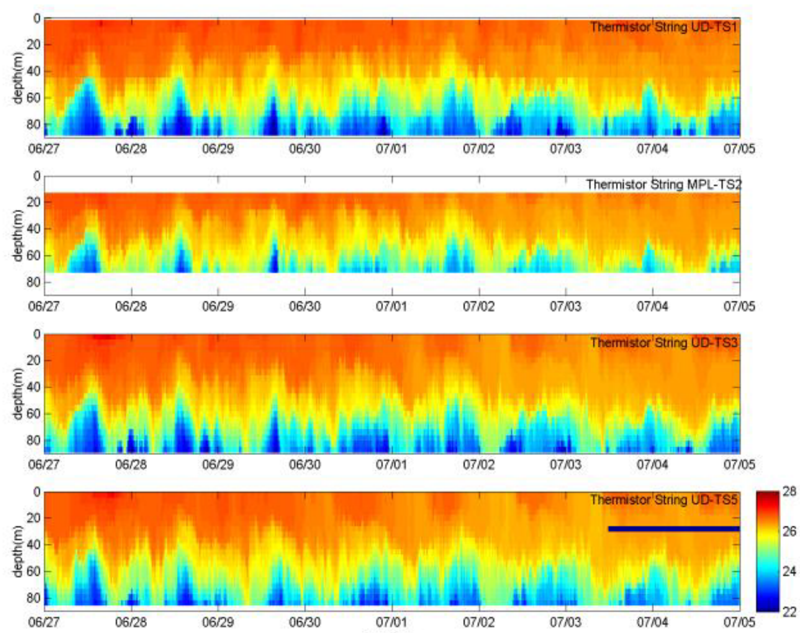

Figure 6: Temperature profiles recorded on each of the four thermistor-strings throughout the 16-day period of the experiment.

The propagation conditions associated with this environment are indicated in Figure 7. We can see a number of paths trapped in the lower duct as well as steeper ray families traveling through the mixed layer and reflecting off the ocean surface (and then the ocean bottom). The red band in Figure 8 shows the position of the UW VLA. In Figure 9 we see the impulse response function on one of its phones, derived by matched filter processing. A variety of ray arrivals are clearly visible. With a little incoherent averaging, the arrivals emerge well above the background of noise and scattered energy. With the aid of a ray trace one can then readily identify the various paths as shown in Figure 9.

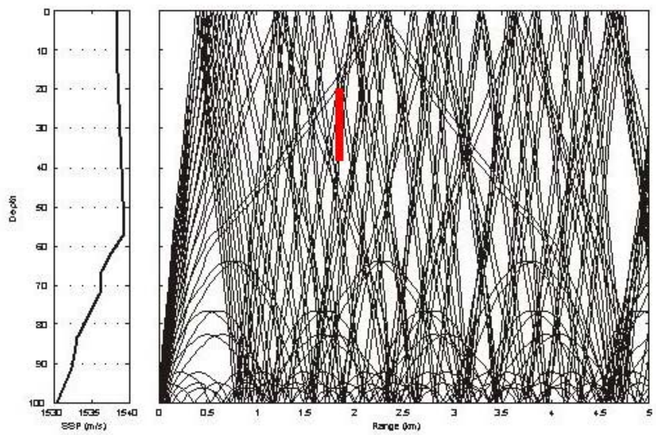

Figure 7: Ray trace from the testbed source on the bottom.

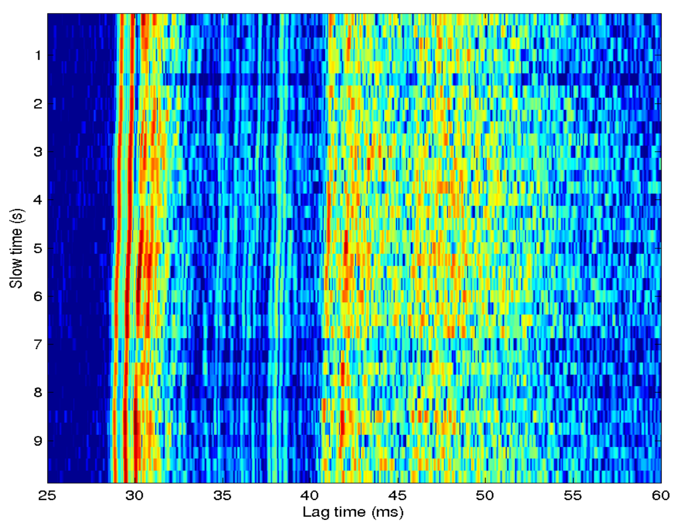

Figure 8: impulse response function measured on the UW array.

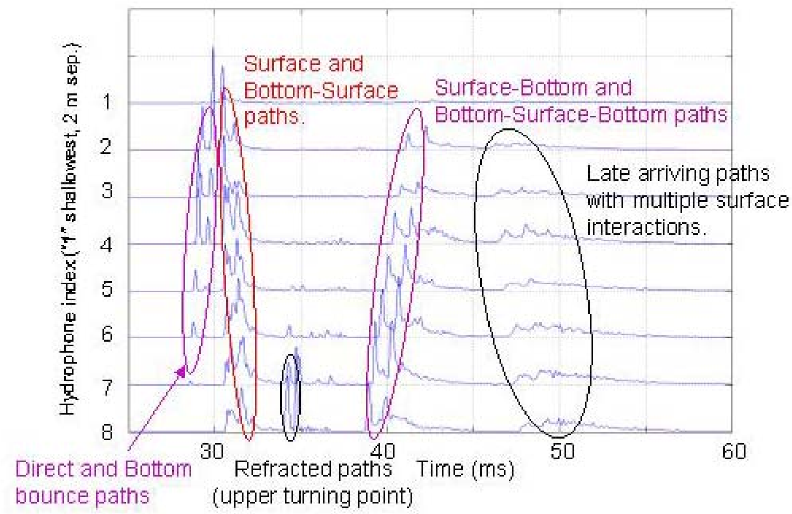

Figure 9: Identification of the various arrivals on the UW array.

A source tow using the SPAWARSSC telesonar testbeds was also made in all the deployment phases to characterize the variation of the channel impulse response as a function of range. Figure 10 shows one such tow. Figure 11 shows that the channel supported a clear multipath pattern; however, when the source depth was decreased midway through the tow, the paths with an extra surface bounce were lost in a reverberant haze.

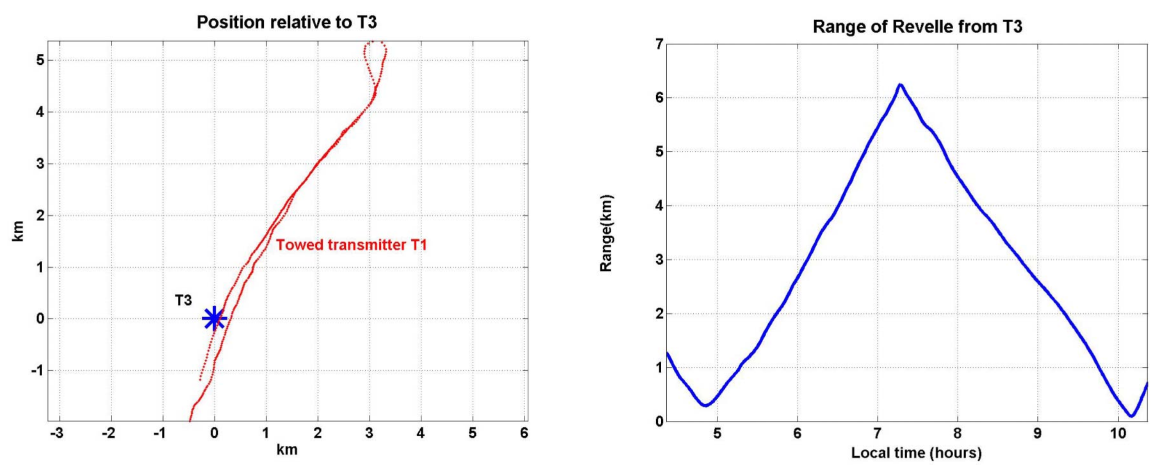

Figure 10: Towed-source events were also included.

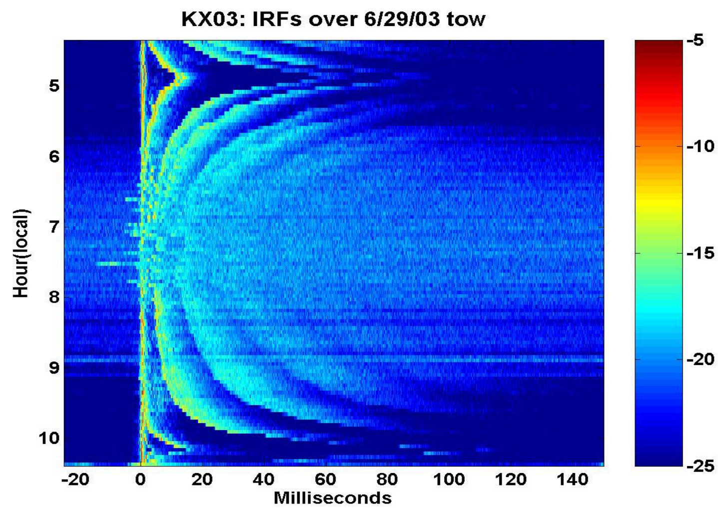

Figure 11: Impulse response function measured during a source tow

Since the MPL vertical line arrays spanned the whole water column, they provided a unique look at the impulse response throughout the ocean channel. Figure 12 shows a snapshot of this data showing the accordion pattern of arrivals as the wavefronts washed across the array. An important issue in observing the impulse response is the number of 'pings' that are averaged together to estimate the channel impulse response. With a single ping (top panel) we can make out the impulse response pattern but there is a lot of background noise (primarily scattered energy). Using an average of 10 pings (middle panel) we get a fairly clear picture of the higher-order arrivals. Passing to an average of 40 pings (bottom panel) we can make out still more of the higher-order arrivals; however, we start to smear out some of the earlier arrivals. The bright blob of energy near the bottom is associated with rays trapped in the lower duct. These are also called whispering gallery or bouncing ball modes.

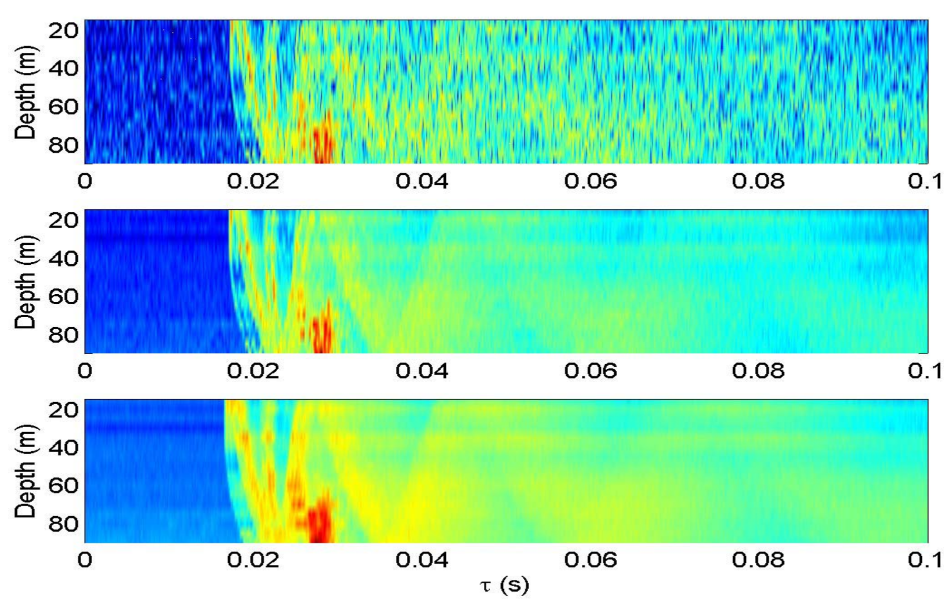

Figure 12: Accordion pattern of echoes as observed on the MPL array. Top panel is a single chirp; middle panel is an average of 10 chirps; bottom panel is an average of 40 chirps.

IMPACT/APPLICATIONS

There are a variety of Navy systems that operate in this frequency band. However, a key application of interests is acoustic modems.

TRANSITIONS

This work is being conducted in parallel with the 6.2 SignalEx program (322OM) on underwater acoustic communication so that lessons learned about the basic propagation physics can be immediately linked to modem performance. The SignalEx program in turn transitions to operational modem development through other 6.3/6.4 navy programs. An example of the latter is SeaWeb, which is an anticipated component of the Assured Access fleet exercise.

RELATED PROJECTS

The Kauai Experiment involved more than 30 participants from various institutions and with varying support. The University of New Hampshire (Christian de Moustier, Brian Calder, Barbara Kraft) conducted the bottom mapping as part of an SBIR to study how tomographic data could improve the mapping accuracy. The University of Mississippi (Jerry Caruthers) conducted the sidescan survey under separate ONR 321OA support. Transmitters and receivers in the SWTR range were also a key part of this experiment in work conducted by Scientific Solutions (Peter Stein). That component was funded through CEROS to examine the assimilation of HF tomography data in an ocean circulation model for the range.